



## Solid-State Electronics



A new child in the radio engineering family has grown to astonishing stature during the last few years. Its personality is so radically new and its future is so promising that there can be little doubt that we are witnessing the early stages of a new era in radio-electronics, the solid-state electronics era.

"Solid-state electronics" may be described broadly as dealing with the control and utilization of the electric, magnetic, and photic properties of solids. The knowledge that special effects can be produced in some materials when energized by electric or magnetic fields or by light is not new. Early investigations of these properties by scientists date back to the last century. Nor is the application of solid-state materials in radio new. One can go back over the years and find several examples, notably in detectors, rectifiers, resonators, and transducers.

It is only recently, however, that we have begun to make real headway in understanding and utilizing solid-state materials on a large scale. We now see ferromagnetic and ferroelectric substances employed for memory cells, ferrites for microwave attenuators, photoconductors for automatic headlight dimmers, and electroluminescent materials for experimental light amplifiers, to name but a few.

The most startling progress to date has been in the field of semiconductors. The development of the transistor in 1948 was a major milestone in electronic progress and already this subject alone has become a major field of endeavor. And yet the transistor represents only one of several species of phenomena inherent to germanium (or silicon), germanium is only one genus of semiconductor material, and semiconductors are only one order

in the family of solid-state materials. There remain many other species, genera, and orders to be further explored and utilized and many other devices to be developed.

Most of our fundamental knowledge about solid-state materials has been developed by physicists, chemists, and metallurgists, and much of this information has not yet filtered across to the engineer. In order for the radio engineer to use these materials in the creation of new devices he must first have some understanding of their fundamental properties. It is to this end that the IRE is devoting this special issue of its PROCEEDINGS to Solid-State Electronics—to bridge the gap between the scientist and the engineer.

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In this issue leading authorities in the field have been invited to discuss the principal classes of solid-state materials, their properties, and their applications. These discussions review prior work in the field, outline in tutorial fashion our present understanding of the subject, and indicate in what direction future progress lies. Emphasis is given to those topics about which little has heretofore appeared in the engineering literature, especially to those materials which can generate, store, or are actuated by light.

The issue starts with a tutorial introduction by Frank Herman to a subject which is basic to an understanding of solids; namely, crystals. The reader will find that this discussion of crystal geometry, energy band structure, and electrical and optical properties will provide him with an excellent vantage point from which to view with greater clarity all of the papers that follow.

Ferroelectric materials are of considerable interest today because of their applications as electro-mechanical transducers and computer memory elements and because they exhibit useful dielectric properties which are quite similar to the magnetic properties of ferromagnetic materials. The next paper (Jaynes) briefly explains the physics of nonlinear dielectrics and is followed by a detailed discussion of ferroelectric crystals and their dielectric behavior (Shirane, Jona, and Pepinsky).

The next group of papers deals with what is thus far the most important class of solid-state materials—semiconductors. The history of semiconductor research (Pearson and Brattain) is not only a very interesting story in itself, but provides some valuable object lessons on how slow we are to accept new ideas and give up old ones. The most useful semiconductor device to be developed so far is the junction transistor. Thanks to intensive research we now have an almost complete understanding of how it works and are making steady progress in improving its performance (Moll). The widespread use of germanium and silicon for transistors and rectifiers has tended to obscure the fact that these materials are also excellent photoconductors (Schultz and Morton) and are already being put to good use as such.

The subject of photoconductors leads us into the general area of photoelectronic phenomena, an area which is very new and very promising. The recent knowledge gained from work on silicon and germanium has led to a much better understanding of photo-effects in intermetallic semiconductors (Frederikse and Blunt), has greatly stimulated research into the use of cadmium and zinc compounds for photoconductors (Bube), and in general has provided considerable insight into the basic mechanism by which the conductivity of a material is increased by exposure to light (Rose). Important strides have recently been made also in the development of lead salt photoconductors for use in infrared detectors (Moss).

As a result of the above advances in photoconductivity, together with the very recent and rapid progress in the development of electroluminescent materials, a great deal of attention is now being given to light amplifiers and related devices. Several successful experimental models have been announced just within the past year and predictions are now frequently heard of the many new wonders which are waiting around the corner, such as picture-on-the-wall television. Among the devices currently being developed is a storage light ampli-

her (Rosenthal). Once an image is projected onto its screen, the projector may be turned off and the screen will store and continue to reradiate the image, but at an intensity no greater than the projected image. This is not to be confused with a true light amplifier (Kazan and Nicoll) which reradiates a greatly intensified image, but only as long as the projector is on. Numerous other uses of photoconductive and electroluminescent cells are being investigated, including color converting screens, counting and switching devices, and logical networks for computers (Loebner).

It can be seen from the above that not only is there great practical interest in photoconductive or light-actuated materials, but also in luminescent or light-generating substances. Recent advances in our knowledge of cathodoluminescence, or electron-excited luminescence (Garlick), are having an important bearing on the study of cathode-ray-tube screen performance and efficiency. Another important type of luminescence can be obtained in some materials by application of an electric field. A thorough understanding of this phenomenon, called electroluminescence, will be of interest and importance to all engineers because of the host of applications it suggests (Destriau and Ivey). Our study of luminescence would not be complete without a survey of present views regarding the constitution and preparation of phosphors (Kroger).

The next paper (Gorter) deals with a class of material which in a relatively short time has found widespread application throughout the radio engineering field, both as perhaps the most popular form of storage element in computers and in providing for the first time practical nonreciprocal devices for the microwave art. This discussion of ferrites, their chemistry, how they are prepared, the history of their development, and their many applications closes the issue.

#### ACKNOWLEDGMENT

We wish to express our deep appreciation to Lloyd T. DeVore, general manager of the Stewart-Warner Electric Division and former manager of the General Electric Co. electronics laboratory, for accepting and discharging so well the heavy responsibility of planning the contents and procuring the material for this entire issue. He has succeeded in bringing together an outstanding group of papers that bring into engineering focus a many-faceted field of science which will profoundly affect the future of radio engineering.—*The Editor*